

Investigations on Transverse Beam Break Up Using a Recirculated Electron Beam*



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- TBBU
- S-DALINAC
- Variation of transverse phase advance
- Variation of chromaticity
- Future plans
- Outlook



Bundesministerium
für Bildung
und Forschung

*Work supported by the BMBF through grant No. 05K13RDA



Beam Break Up (BBU)

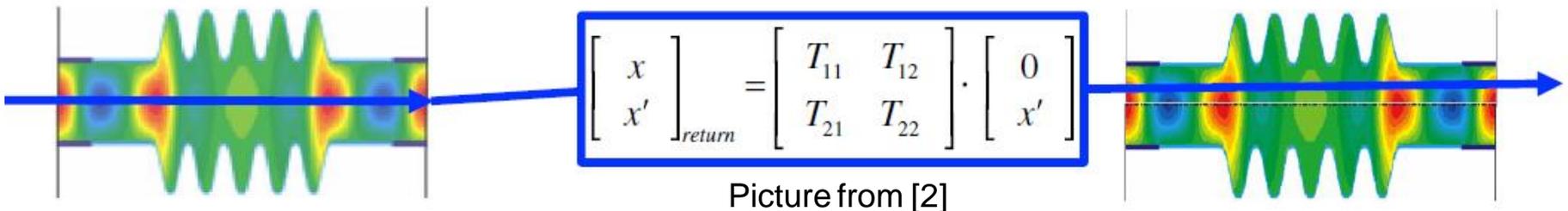
- Transverse beam break-up (BBU) occurs when an accelerated beam excites higher order dipole modes (HOM) in the superconducting accelerating cavities
- Some of these modes can have a high quality factor and thus a long lifetime and deflect the following bunches

- BBU threshold current:

$$I_{th} = \frac{2c^2}{e \cdot R_g \cdot Q \cdot \omega} \cdot \frac{1}{T_{12} \sin(\omega t_r)} \quad [1]$$

(for one cavity and recirculations and for the worst HOM)

- In recirculating design this can be even worse $\rightarrow I_{th}$ scales with $1/N^2$



[1] G.H. Hoffstaetter, I.V. Bazarov, Phys. Rev. ST – AB **7**, 054401 (2004).

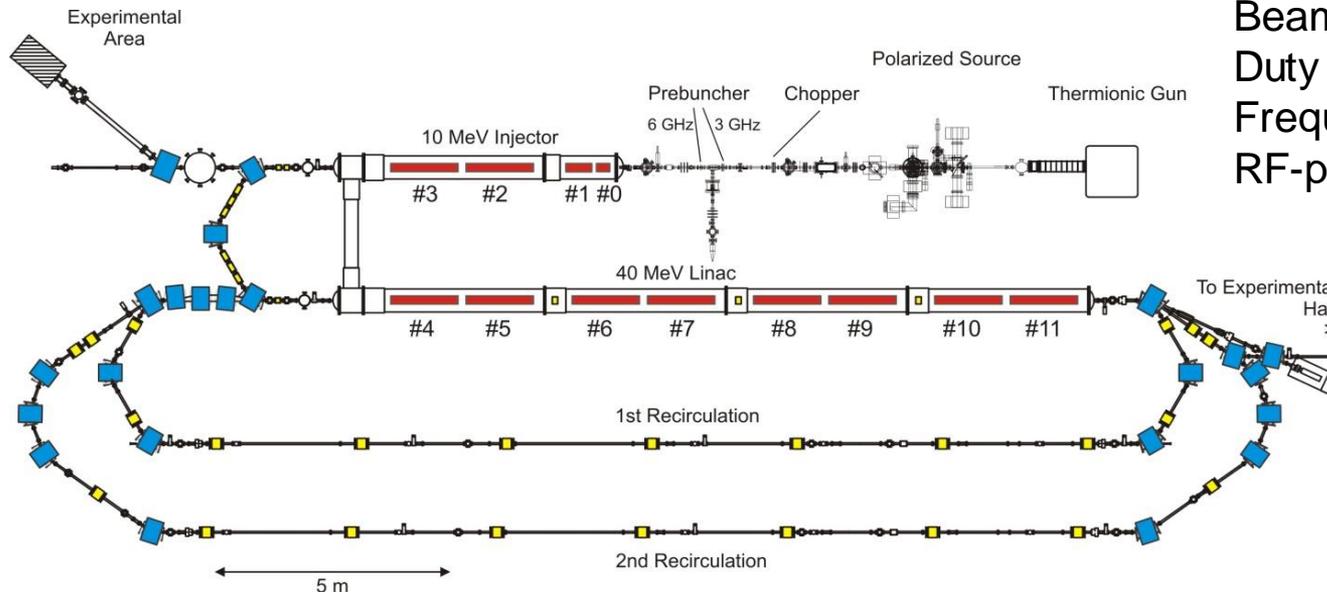
[2] V. Litvinenko, Phys. Rev. ST - AB **15**, 074401 (2012).

S-DALINAC

Superconducting DArmstadt LINear Accelerator

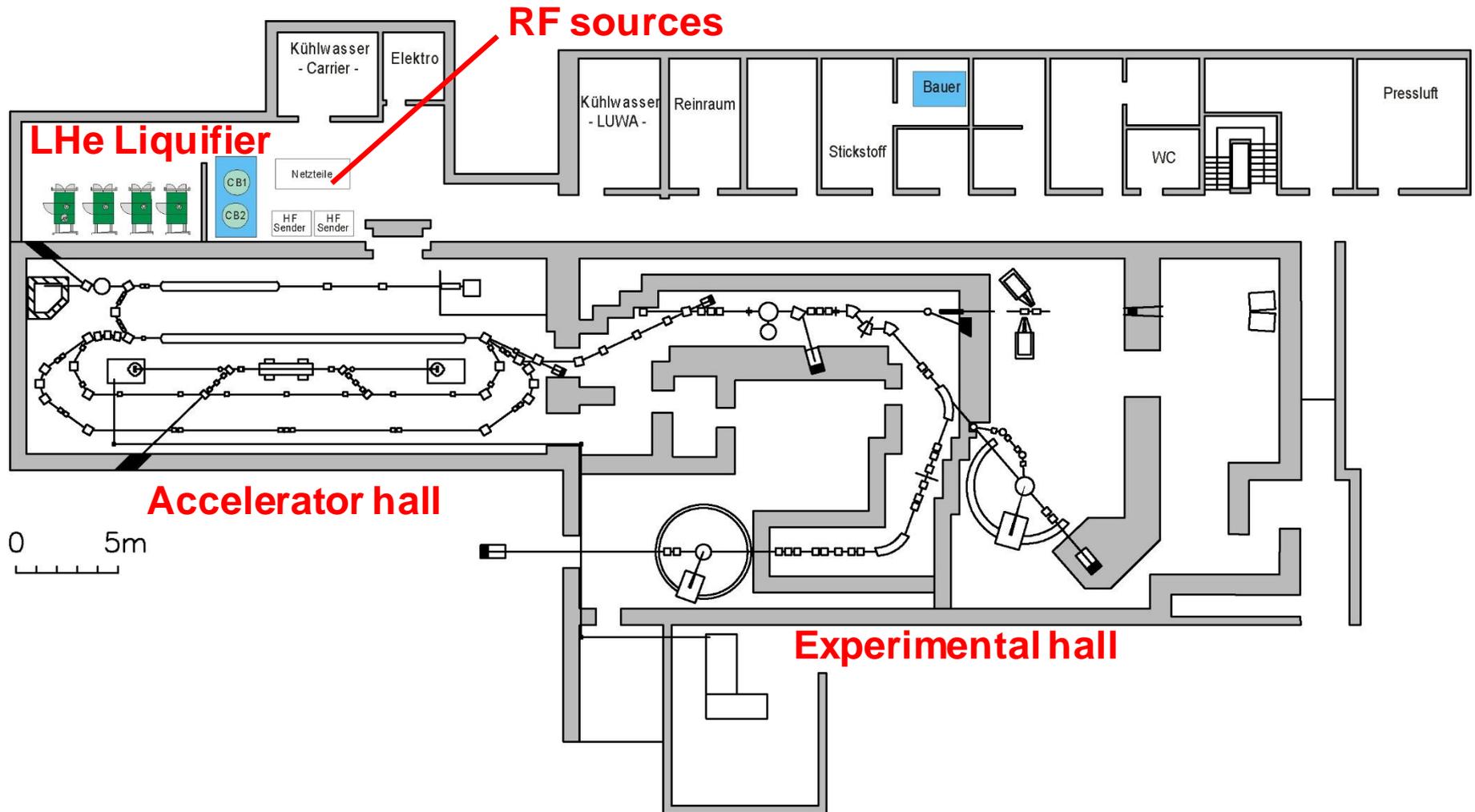
Design Parameters:

Max. Energy:	130 MeV
Beam Current:	20 μ A
Duty cycle:	cw
Frequency:	3 GHz
RF-power/cavity:	500 W

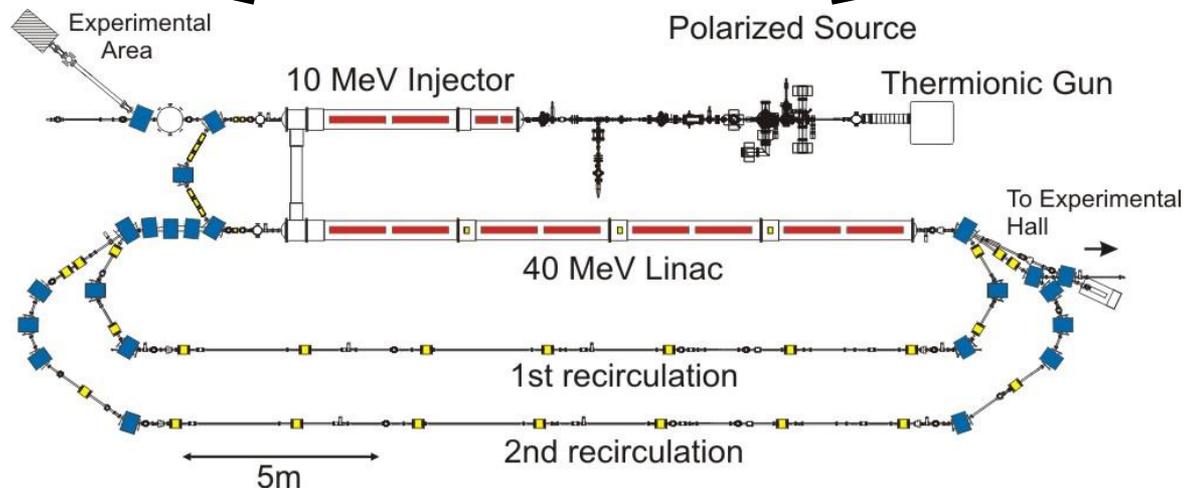
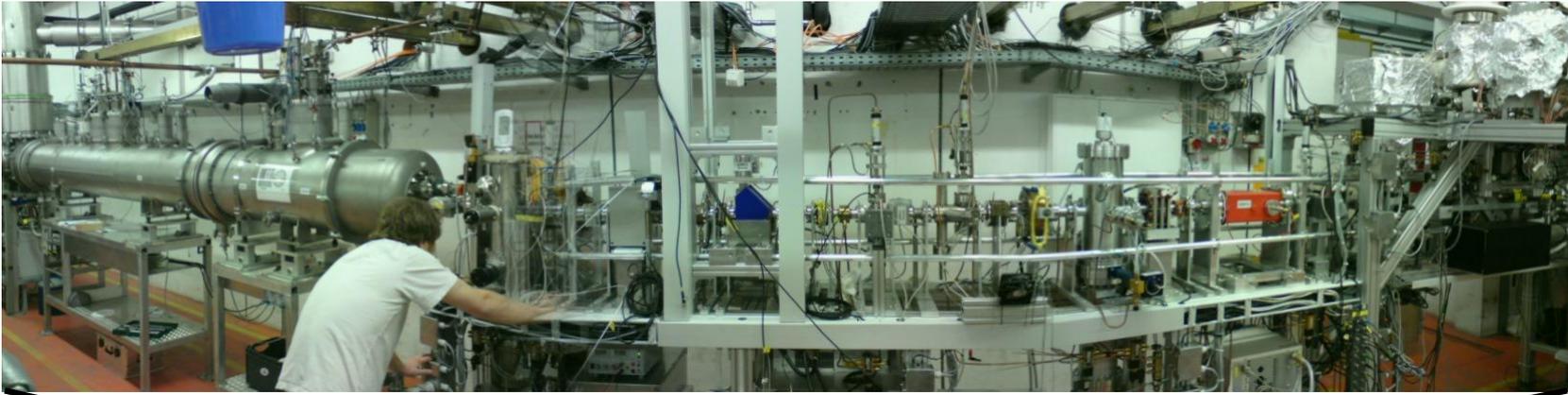


- Built in the 1980s
- First beam in 1987
- 1991 first recirculated beam
- Liquid helium @ 2 K
- Kryoplant: 100 W cooling power
- 12 SRF Cavities

S-DALINAC Complete facility



S-DALINAC Injector



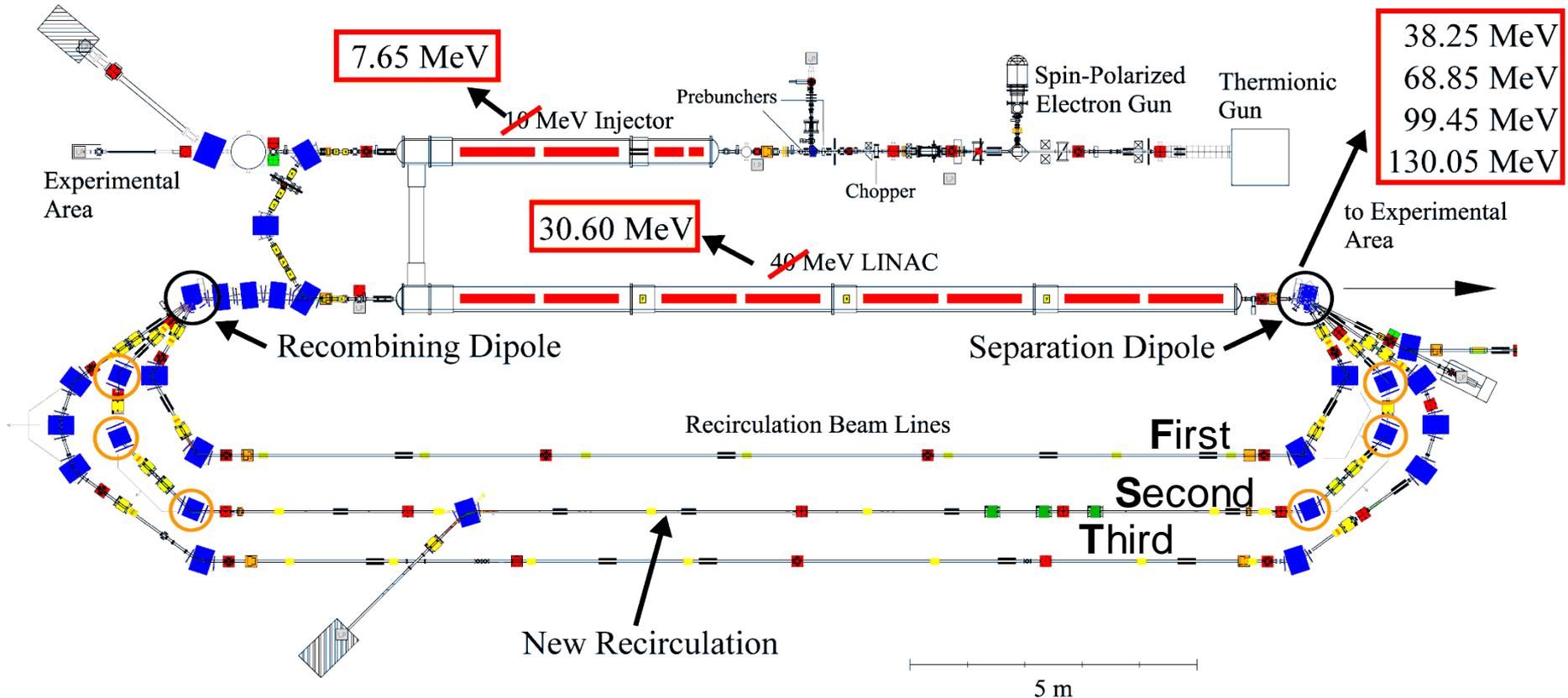
S-DALINAC Accelerator hall



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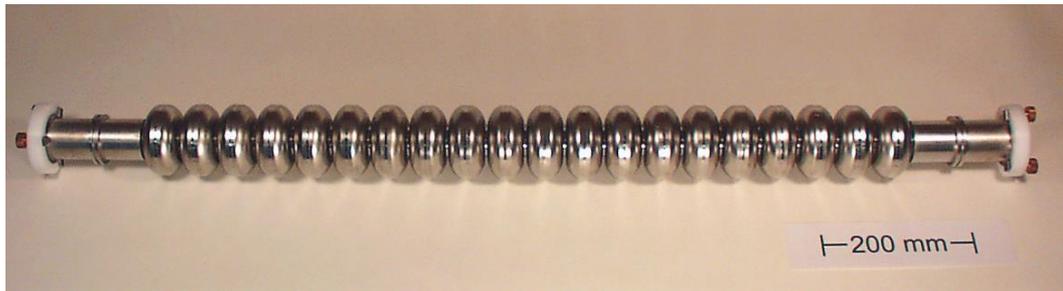


S-DALINAC UPGRADE (finished in Jan 2016)



- Single pass, one or three recirculations will be possible
- Installation begins in summer 2015 (Ph.D. thesis of Michaela Arnold)

S-DALINAC Cavity



20 cells

1 m length

Material:	niobium
Freq.:	2.997 GHz
Mode:	$TM_{010,\pi}$
Temp.:	2 K
E_{acc} :	5 MV/m
Q_0 :	$3 \cdot 10^9$
P_{dis} :	4.2 W

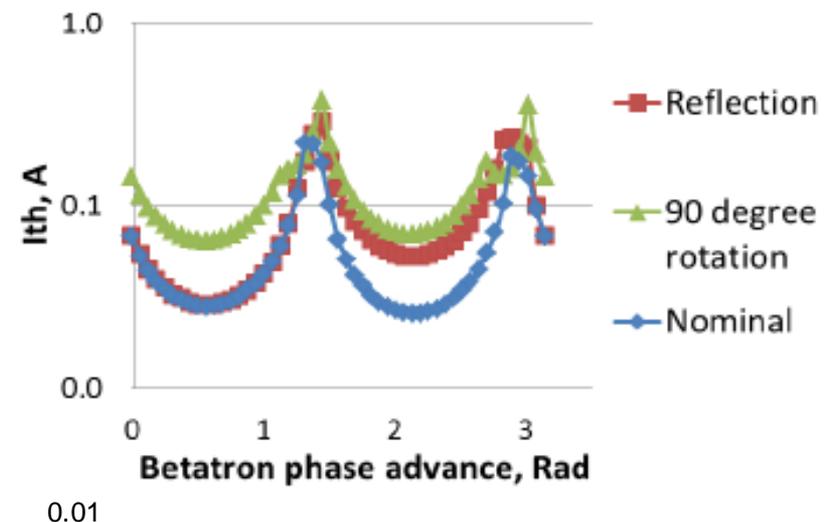
- Using 8 cavities in main linac
- Cavities were **not** designed to minimize any HOMs
- **No** HOM-Couplers
- Max. current of 20 μA was never reached with recirculated beam

Variation of transverse phase advance

BBU threshold current:

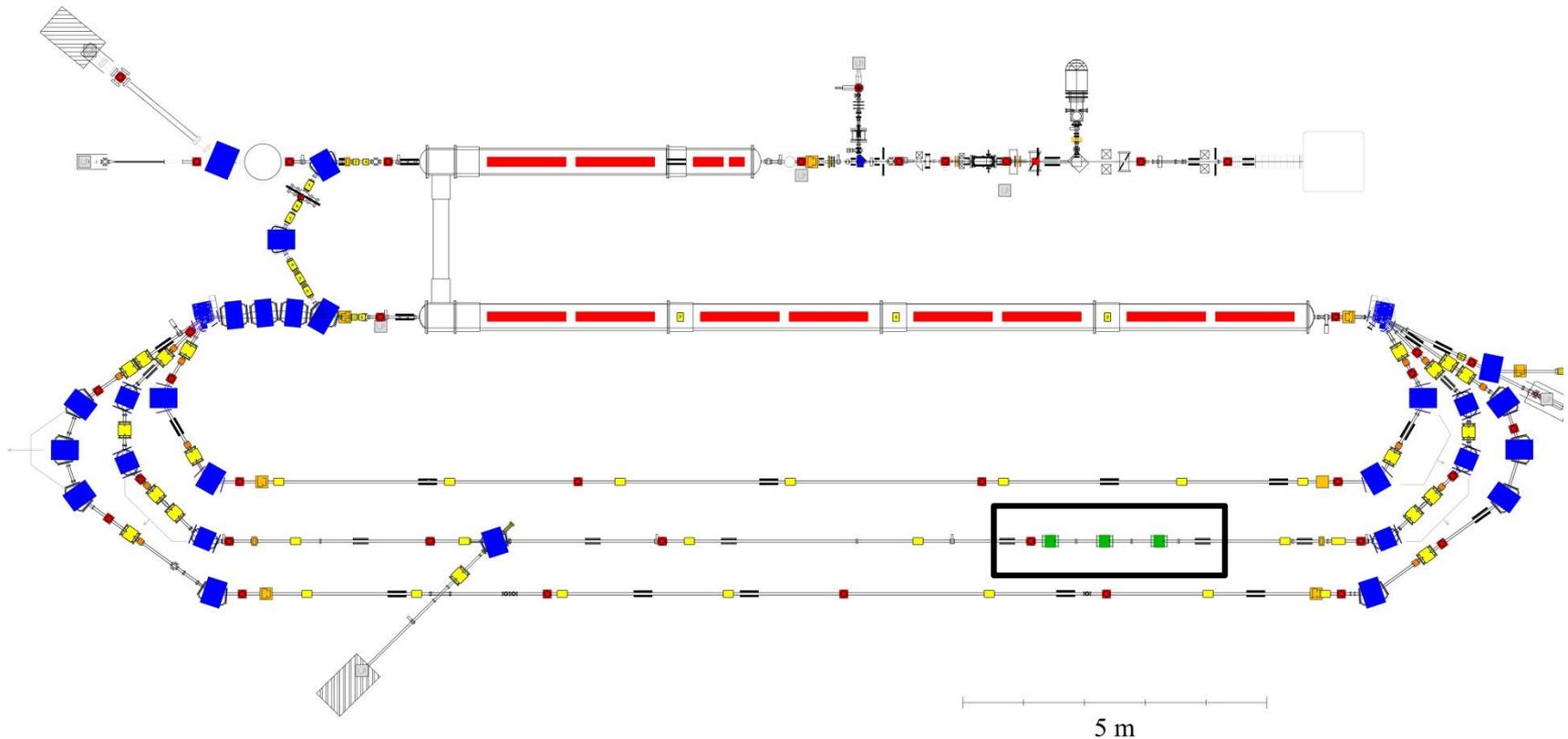
$$I_{th} = \frac{2c^2}{e \cdot R_g \cdot Q \cdot \omega} \cdot \frac{1}{T_{12} \sin(\omega t_r)}$$

- T_{12} can be set up very variable in S-DALINAC recirculations. Experiments will aim on a systematic variation of this value
 - But: You need to know the HOMs of the accelerating cavities
 - **Coupling** x and y planes of motion can increase threshold current even further
- Use solenoids or skew quadrupoles [3] Y. Petenev et al., IPAC'11, San Sebastian (2011) 718. to achieve such coupling



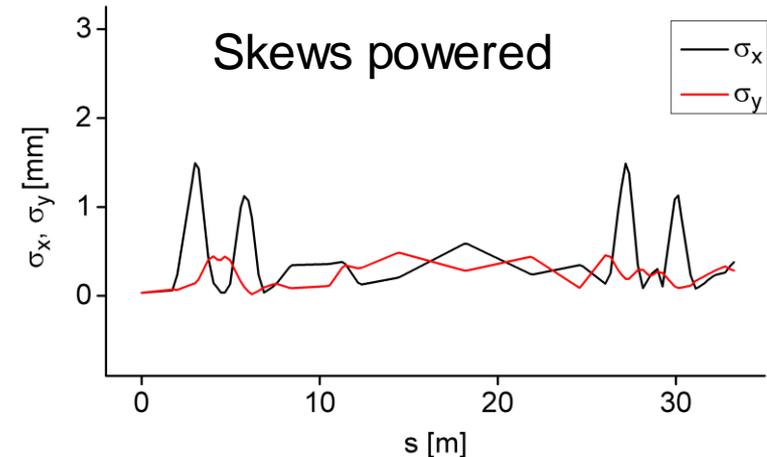
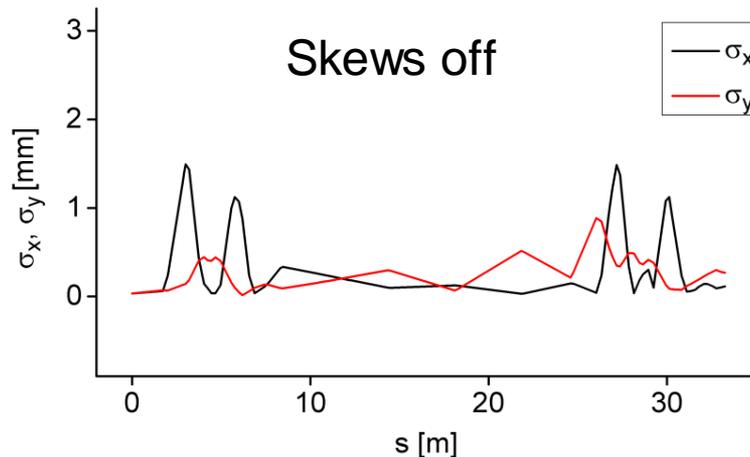
Variation of transverse phase advance: Plan for S-DALINAC UPGRADE

- Place 3 skew quadrupoles in the new (second) recirculation beamline



Variation of transverse phase advance: Plan for S-DALINAC UPGRADE

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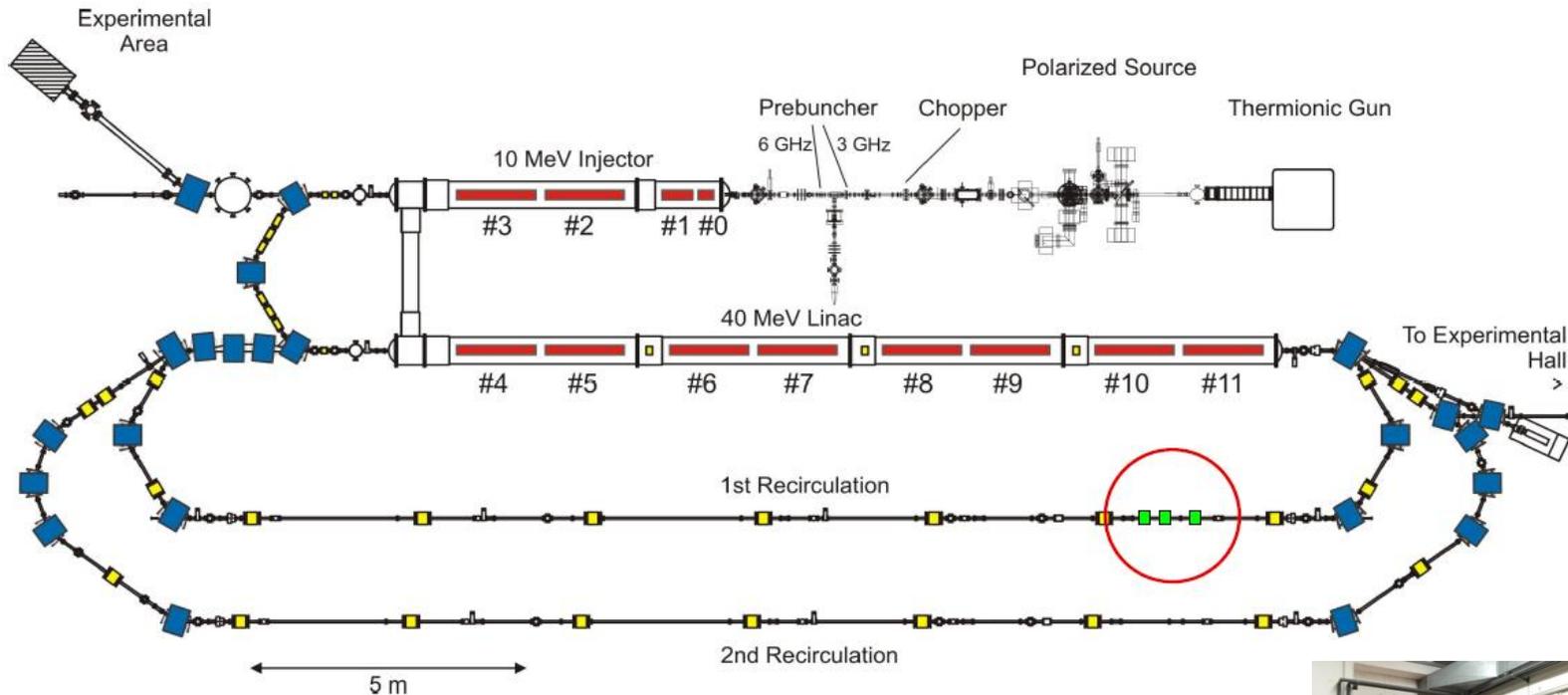


Envelopes of the S – beamline (Simulation software: *elegant*)

- Transfer from x-plane to y-plane, complete phase space exchange
- Only minor refocussing on the straight section is needed for proper beam transport

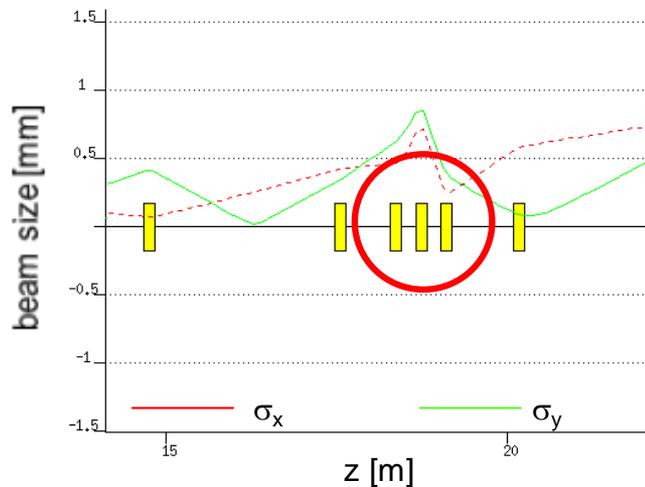
Variation of transverse phase advance: Upcoming tests

- Added 3 skew quadrupoles in the first recirculation beamline

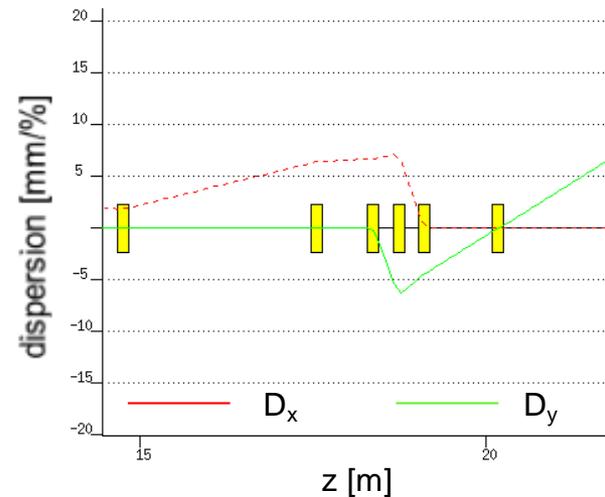


Variation of transverse phase advance: Upcoming tests

- Add 3 skew quadrupoles in the first recirculation beamline (*xbeam*-Simulation):



→ Impact on transverse focussing tolerable



X-dispersion transferred in Y-direction
→ Complete phase space exchange

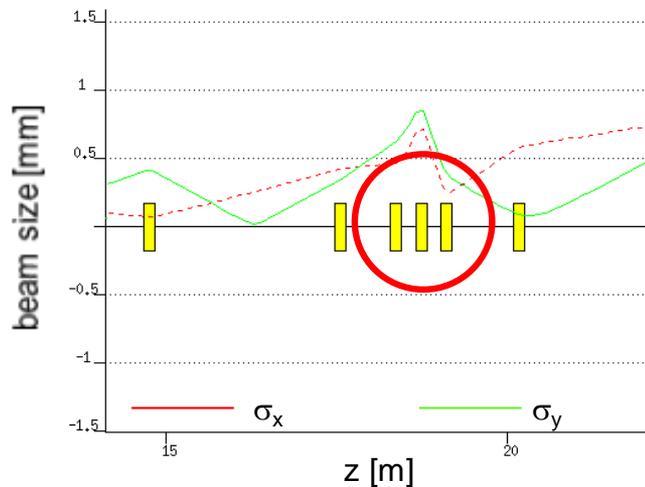
Quadrupole strengths needed:

QU1 = 2.8 T/m, QU2 = 3.7 T/m, QU3 = 4.6 T/m @ 50 MeV
(max. achievable gradient of used magnets: 6.5 T/m)

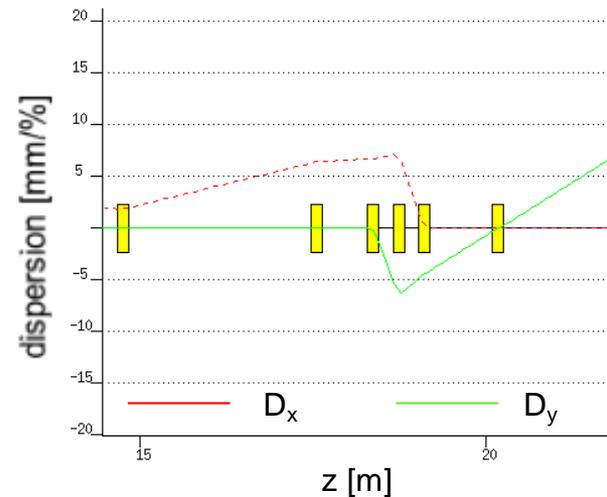


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Tests can be made next month



Variation of chromaticity

- Again: reduce T_{12}

$$I_{th} = \frac{2c^2}{e R_g \cdot Q \cdot \omega} \cdot \frac{1}{\sum_{J=1}^{2N} \sum_{I=J+1}^{2N} T^{IJ} \sin \omega(t_I - t_J)}$$

- Calculations [2] for large scale recirculating linac (eRHIC at BNL) predict another strategy of overcoming BBU:

Use the natural chromaticity in the beam transport system instead of correcting for it

- Particles might „forget“ their transverse kicks when

$$\left| \xi \frac{\Delta E}{E} \right| \gg 1 \quad [2]$$

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- Typical energy spread: $\frac{\Delta E}{E} \approx 10^{-3}$

- Natural chromaticity of the S-DALINAC is too low (~ 100)

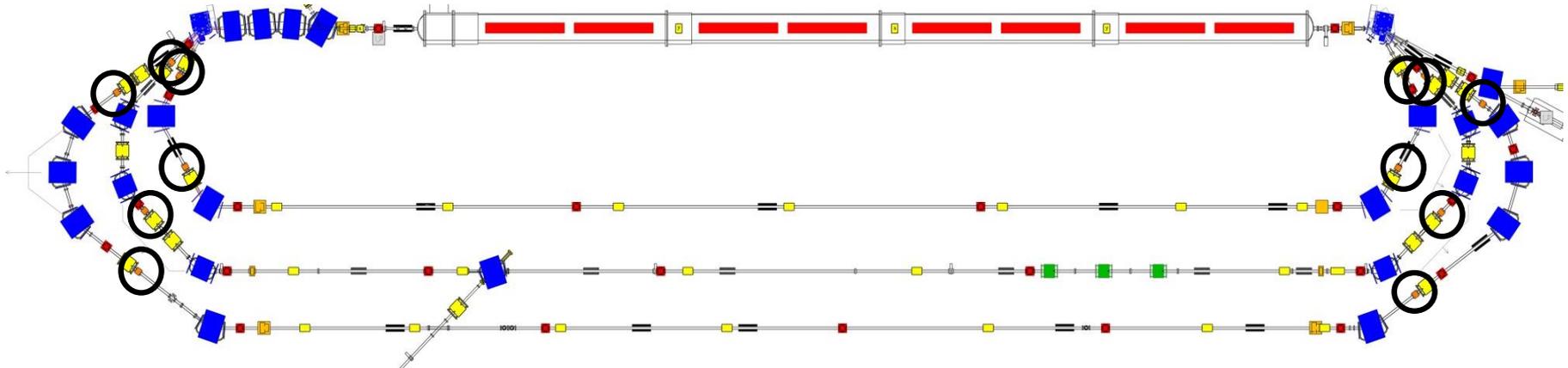
[2] V. Litvinenko, Phys. Rev. ST - AB **15**, 074401 (2012).

Variation of chromaticity: Use of sextupole magnets to increase ξ

Idea: Place sextupole magnets in the arcs to increase ξ

- Positioning: Regions of high dispersion

$$\xi = \frac{1}{4\pi} \oint (m(s)D(s) + k(s)) \beta(s) ds$$



Variation of chromaticity: Sextupole magnets

Laminated sextupole magnets

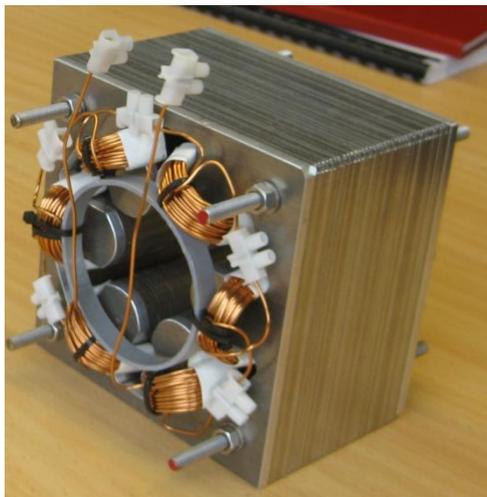
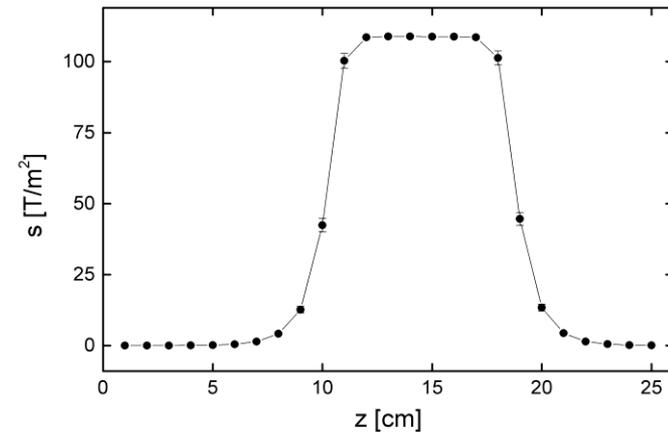
12 manufactured

Current: 7 A

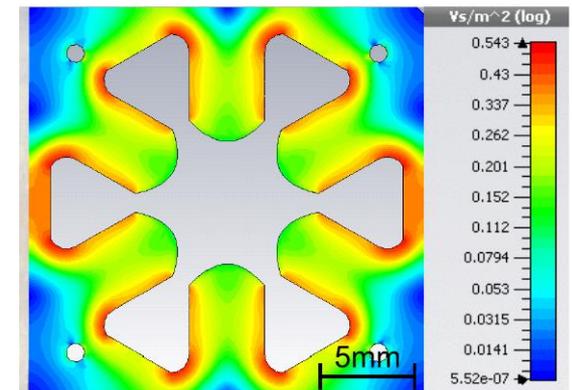
Windings: 35

Magn. length: 9 cm

Field profile of sextupole magnet at 7 A

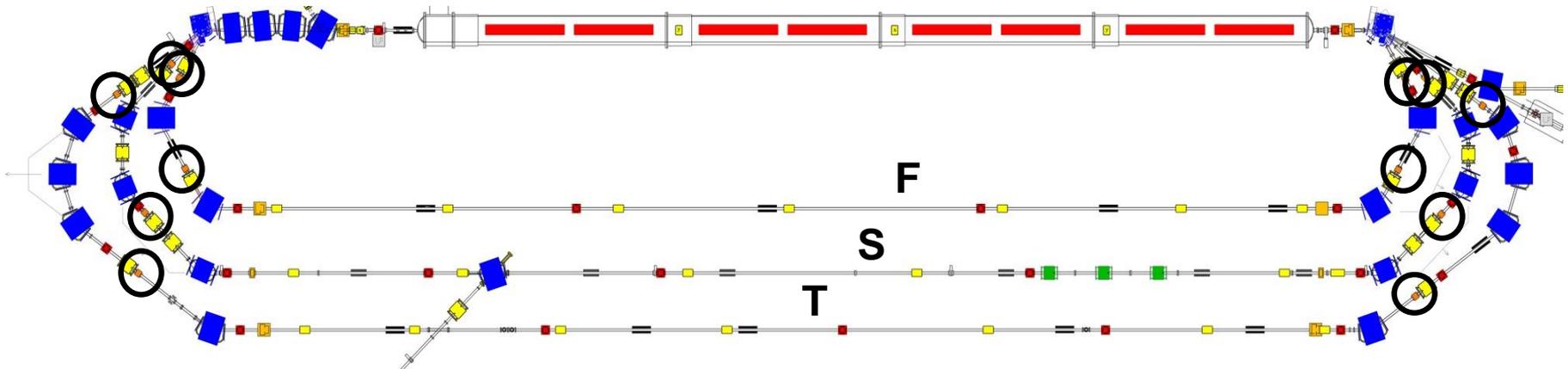
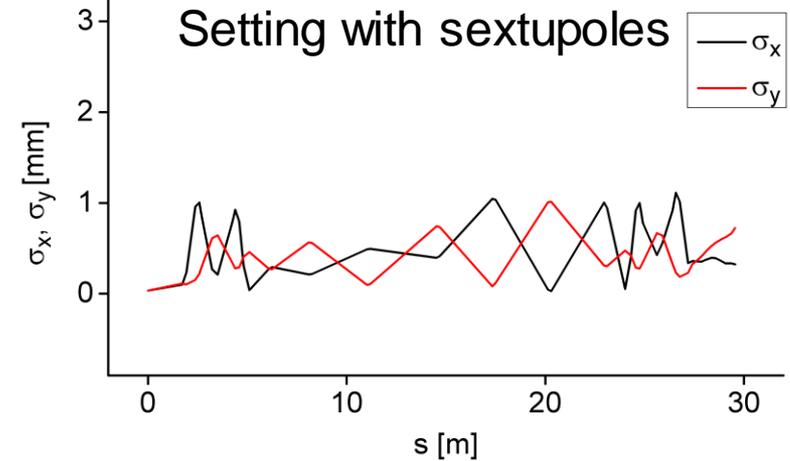
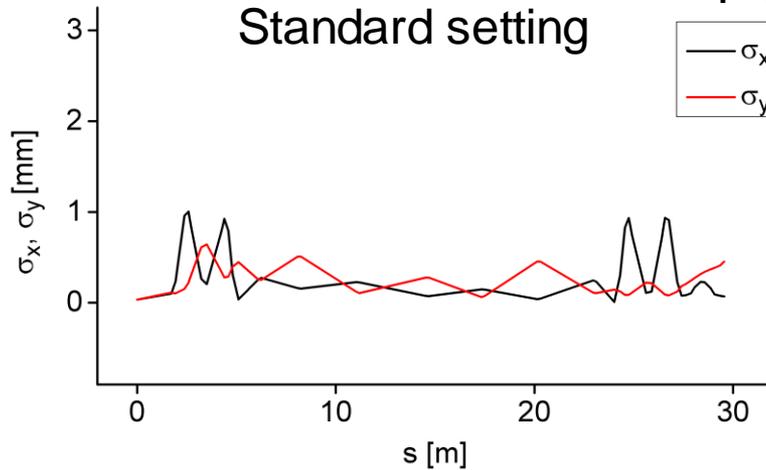


Designed and build in house



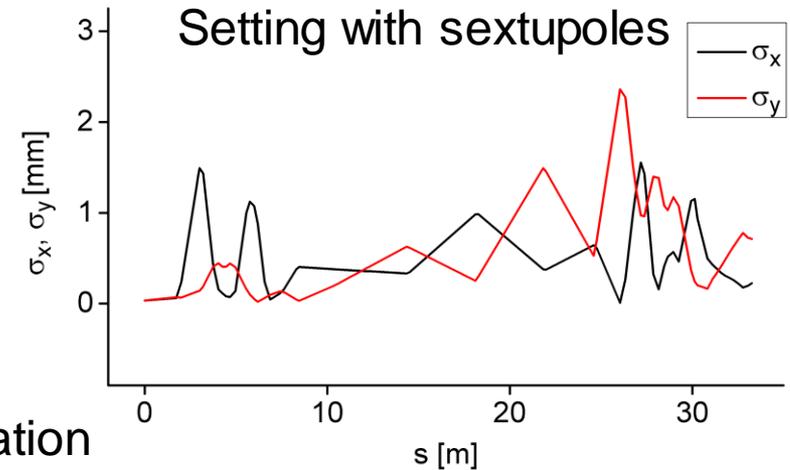
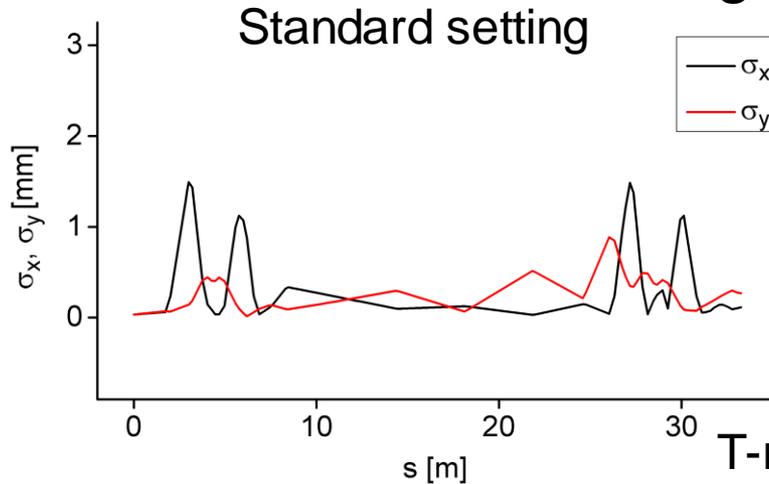
Variation of chromaticity: Beam dynamics

F-recirculation

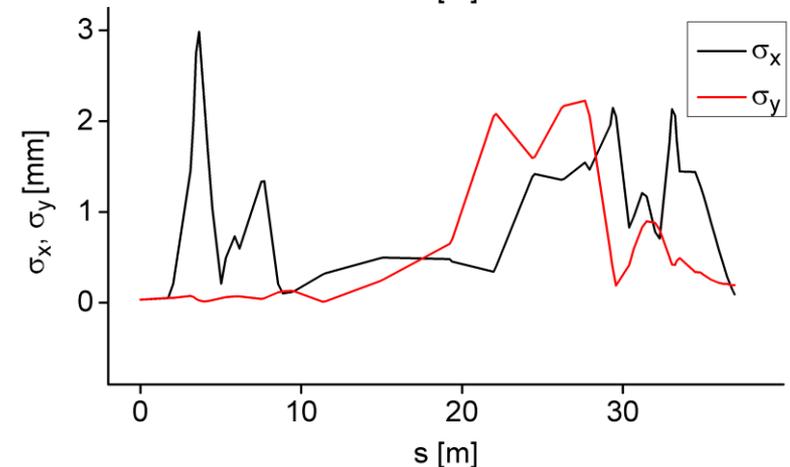
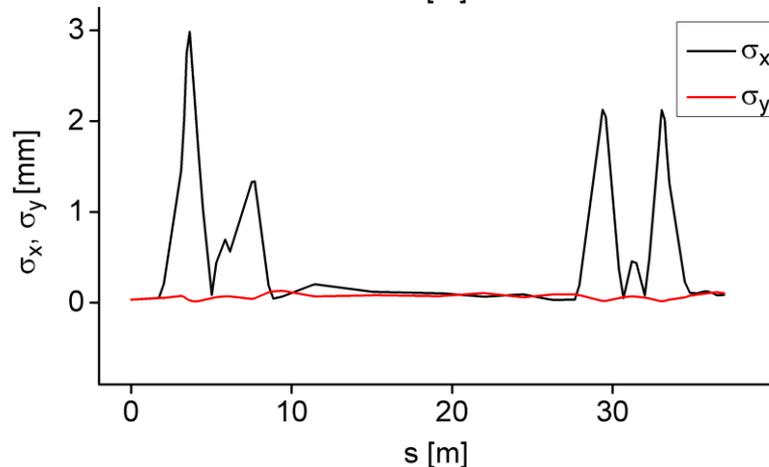


Variation of chromaticity: Beam dynamics

S-recirculation



T-recirculation



Variation of chromaticity: Beam dynamics



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Results for the chromaticity: $(E=130 \text{ MeV}, \Delta E/E = 2.5 \cdot 10^{-3})$

First: $\xi_x = -2765, \xi_y = 1073$

Second: $\xi_x = -1026, \xi_y = 1744$

Third: $\xi_x = -1590, \xi_y = 2862$

- With the energy spread this fulfills the condition

$$\left| \xi \frac{\Delta E}{E} \right| \gg 1$$

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- Simulations have to be finalized and finding maybe better and different settings for the different energy and energy spread setting possible

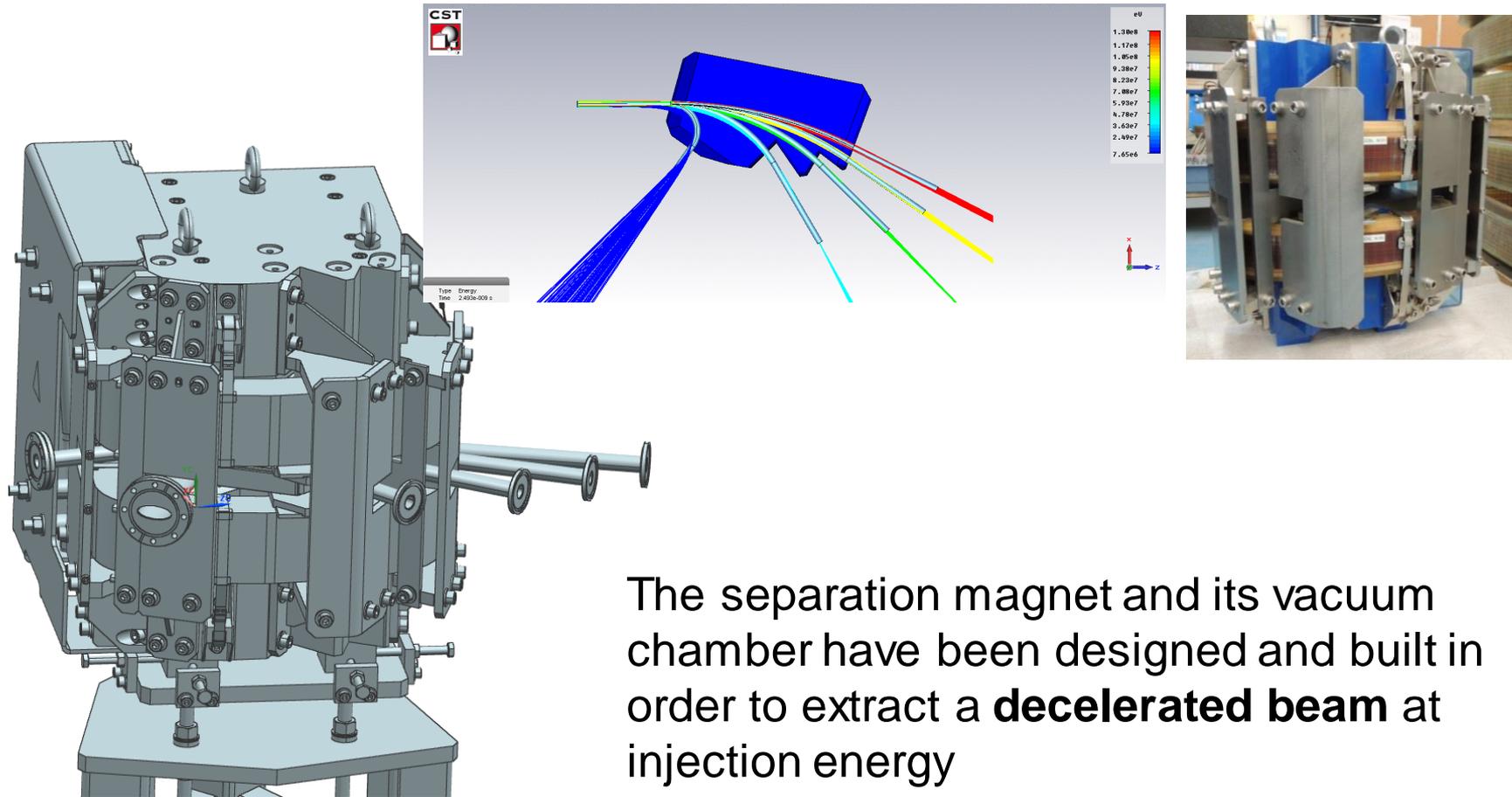
Future plans



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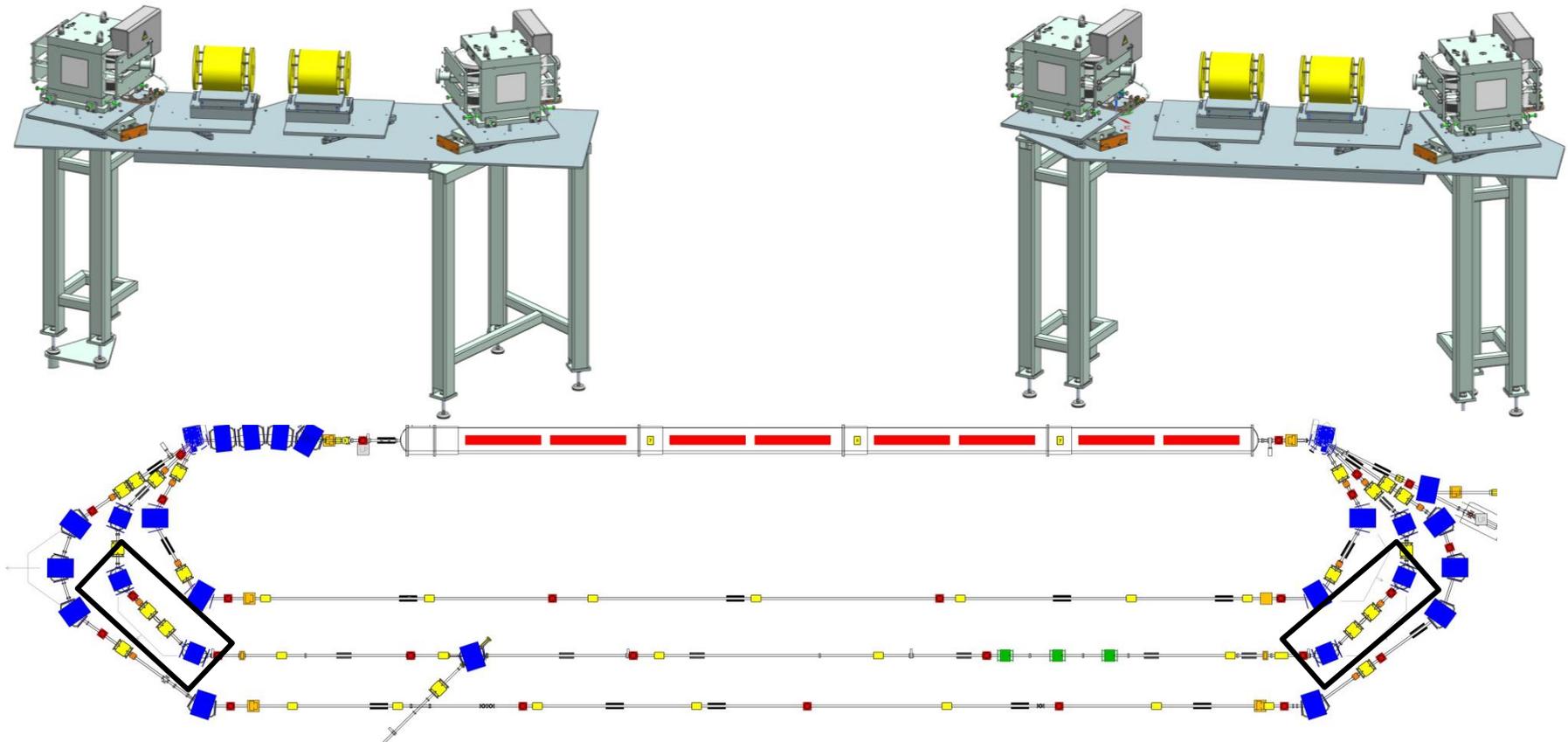
Future plans



The separation magnet and its vacuum chamber have been designed and built in order to extract a **decelerated beam** at injection energy

Future plans

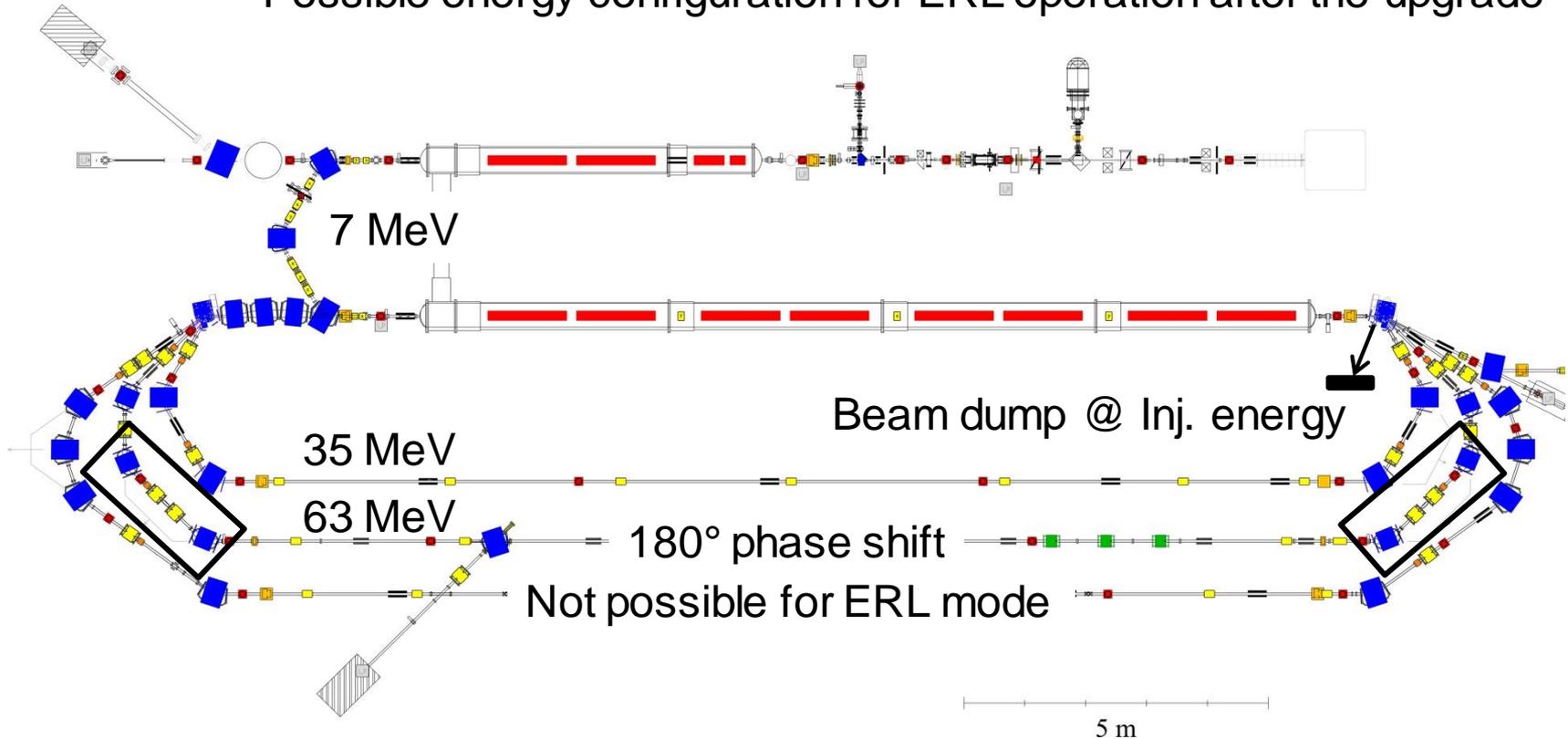
Change of pathlength in S recirculation: $\sim 10 \text{ cm} = 1 \text{ wavelength}$



Future plans: 2016

S-DALINAC as single or double turn ERL

Possible energy configuration for ERL operation after the upgrade



This offers even more possibilities to use the S-DALINAC to investigate on BBU and other ERL related questions

- Test for BBU suppression with skew quadrupoles in the current accelerator setting
- Upgrade the S-DALINAC with another recirculation beamline and integrated sextupole and skew magnets
- Finalize simulations
- Use the S-DALINAC with 3 recirculations for BBU suppression experiments
- Use the S-DALINAC as a single or double turn ERL in the future (2016) for BBU suppression and other ERL science related experiments

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Thank you